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REFLECTOR-BASED POISON-DRUM CONTROL ON EQUAL-SIZE REACTOR CORES FUELED WITH URANIUM-233 AND WITH URANIUM-235

by Wendell Mayo and Robert M. Westfall

Lewis Research Center
Cleveland, Ohio

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16. Abstract

Reflector-based poison-drum control was marginal for a heavily loaded, long-life, high-temperature, fast-spectrum reactor core with a length-to-diameter ratio of about one and using uranium-235 or uranium-233 in the nitride form. A tantalum-based alloy and tungsten were used as fuel-pin cladding and internal core support. Beryllium oxide and molybdenum reflectors were considered as were the number of control drums, the drum spacings, and the poison sector thickness for both reactors. A one-dimensional transport theory program was used for all reactivity control calculations.

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REFLECTOR-BASED POISON-DRUM CONTROL ON EQUAL-SIZE REACTOR CORES FUELED WITH URANIUM-233 AND WITH URANIUM-235

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SUMMARY

A study has been conducted to compare equal-size reactor cores, using uranium nitride fuel enriched in uranium-233 or uranium-235 for reactivity control characteristics using poisoned control drums in the radial reflector. The reactor core contains 24.4 volume percent T-111 (a tantalum-based alloy) and 1.5 volume percent tungsten as fuel-pin cladding and internal support structure. The lithium-7 coolant occupies 25.2 volume percent of the core with the remainder of 48.9 volume percent allowed for fuel and void. The core is about 36 centimeters in diameter and 37.6 centimeters long.

For the particular requirements of the reactor used in this study (2.17 MW (thermal) for 50 000 hr at 1222 K and with a length-to-diameter ratio of 1.04), the calculated reactivity control is marginal for the uranium-235 fueled core. For example, the calculated reactivity control is 6.5 percent $\Delta k/k$ using a drum configuration of 10 drums with 6.35-centimeter-thick annular sectors of boron-10 carbide and with 0.52 centimeter between control drums and 0.75 centimeter between control drums and pressure vessel. The reflector composition was 70 volume percent beryllium oxide, 10 volume percent molybdenum, and 10 volume percent lithium-7. The required reactivity control is 7.0 percent $\Delta k/k$, only 0.5 percent $\Delta k/k$ greater than calculated.

The reactivity control requirements for the same reactor fueled with uranium-233, is 7.9 percent $\Delta k/k$, while the calculated reactivity control is 8.6 percent $\Delta k/k$. Thus the calculated reactivity control exceeds the required amount by only 0.7 percent $\Delta k/k$. Without experimental verification or more sophisticated calculations, the reactivity control for both these reactors must be considered marginal.

Only small differences in reactivity control were found as a function of the number of control drums and as a function of the replacement of the beryllium oxide by molybdenum in the reflector.

INTRODUCTION

Rotating control drums containing an annular sector of neutron absorber appear to be desirable for use in the radial reflector of a high-temperature, fast-spectrum reactor for space power applications. This is true for several reasons. With the entire control system external to the pressure vessel, the number of pressure-vessel penetrations is minimized. Furthermore, the radiation and temperature environment outside the pressure vessel can be considerably less severe than inside. Also, control-drum mechanisms, bearings, and reflector materials are isolated from the primary coolant loop and can be cooled with a separate, lower temperature, loop. A working fluid different from the primary coolant could be considered.

These potential advantages can be realized only if the reactivity control characteristics for the particular reactor are adequate. The purpose of this study is to examine the reactivity control characteristics of poison-drum control for a specific core configuration. The core contains large amounts of a tantalum alloy for fuel-element cladding and structural support. The effect of this parasitic neutron absorber on the reactivity worth of the reflector and consequently on control drum worth is expected to be detrimental. In this study the important parameters associated with the control drums and reflector and the amount of available reactivity control will be determined. A comparison will also be made between the control characteristics of reactors using uranium-233 fuel and those using uranium-235 fuel. Use of the more reactive uranium-233 offers the possibility of longer life or higher temperature cores because of the lower fuel loading requirements which would allow more core volume to be devoted to alleviating fuel clad stresses due to gas pressure and fuel swelling and to fission product gas containment.

One parameter which was not examined is the effect of varying the length-to-diameter ratio (L/D) of the core on the reactivity control. An L/D much greater than 1 is not desired because of increased shield weight requirements for 4π shields. Pumping power requirements would also increase with increasing L/D. Hence the L/D of 1.04 was not varied in this study. However, the effect of increasing L/D is discussed briefly, using data from a previous study, in conjunction with the discussion later on the effect of the number of control drums.

Reference 1 was used as a guide in selecting boron-10 carbide as the control poison and molybdenum as one of the reflector materials. A reflector based on beryllium oxide was also considered in this study because of the potential weight savings compared with molybdenum. Beryllium oxide was rejected for use as a reflector for the fast-spectrum reactor in reference 1 because of the expected power peaking at the core-reflector interface. In later work (ref. 2), however, it is reported that the power peak was all but eliminated by use of a tantalum-based alloy pressure vessel and a 10-volume-percent molybdenum canning material for the beryllium oxide.

The one-dimensional calculational model used in this study is based on work reported in reference 3; in that reference, a similar one-dimensional model predicted a value of reactivity control only 7 percent lower than a more exact value obtained from two-dimensional calculations. For the purpose of this report the values of reactivity control calculated with the one-dimensional model will be reported. The conclusions based on these calculations will therefore be preliminary. Comparison of the effects of parameter variation, such as the number of control drums, computed with the same model will be more definitive.

DESCRIPTION OF THE REACTOR

In the first part of this section the core geometry and materials are described. The same core geometry internal to and including the pressure vessel is used for all parts of this study. The only change made in the core is the substitution of uranium-233 nitride ($U^{233}N$) fuel for uranium-235 nitride ($U^{235}N$) with an appropriate reduction in fuel volume fraction to maintain criticality. In the second part of this section the reflector (radial), control-drum geometry, and materials are described. Also, included are the types of parameters which were examined.

Core Description

The cylindrical core is based on a tube-in-tube design utilizing fuel element pins. A typical cell is shown in figure 1. The fuel pins are 1.91 centimeters in diameter and clad with the tantalum alloy T-111 and tungsten. The T-111 is 0.147 centimeter thick. The

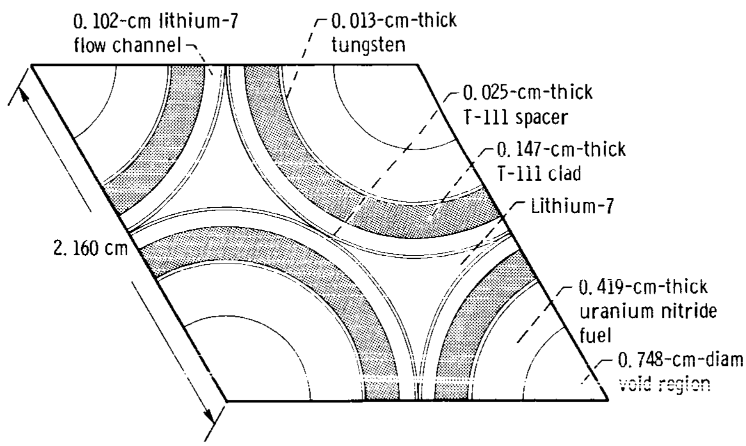

Figure 1. - Lattice cell with fuel and void region dimensions corresponding to fuel volume fraction of 0.380.

0.013-centimeter-thick tungsten layer is located between the T-111 and the nitride fuel. The fuel pins fit within a T-111 honeycomb structure made of contiguous tubes of T-111 which are 2.16-centimeters in outside diameter with 0.025-centimeter-thick walls. The lithium-7 (Li^7) coolant flow passage between the honeycomb tube and the fuel pin is 0.102 centimeter thick. The tricusped area formed between three adjacent T-111 tubes is also filled with Li^7, but this coolant is stagnant. The volume fractions within a cell in the triangular-pitch lattice are

Uranium nitride and void	0.489
T-111:	
Honeycomb	.042
Clad	.202
Tungsten clad	.015
Lithium-7 coolant:	
Active	.159
Stagnant	.093
	1.000

The fuel and void are listed together because the reactor contains three radial fuel zones and because criticality requires different volume fractions depending on whether U^{235} or U^{233} is used.

With U^{235} in the fuel, the loading in the central zone of 73 fuel pins is 33.4 volume percent, in the middle zone of 90 fuel pins it is 37.7 volume percent, and in the outer zone of 90 fuel pins it is 42.0 volume percent. Each zone is arranged to approximate a circular boundary and in one-dimensional cylindrical geometry the core is 36.06 centimeters in diameter. The average loading is 38.0 volume percent leaving an average of 10.9 volume percent for void. The U^{235} fuel is composed of 93.2 percent U^{235} with the remainder being U^{238}.

With U^{233} in the fuel (98.2 percent U^{233}, 1.1 percent U^{234}, 0.7 percent U^{238}), the zoning is 20.6, 23.3, and 26.0 volume percent for the respective zones based on the same fuel pin arrangement. The average loading is 23.5 volume percent leaving 25.4 volume percent for void. The volume percent of fuel in each zone relative to the average in the core is the same for both types of fuel.

The T-111 pressure vessel has a 38.86-centimeter inside diameter with 0.635-centimeter-thick walls. The active core is 37.59 centimeters long. The 10.16-centimeter-thick axial reflectors (85 vol. % Mo, 15 vol. % Li^7) are separated from the core by 2.54-centimeter-thick coolant distribution plenums at each end of the reactor. The plenum region is mostly Li^7 with about 25 volume percent T-111 from the fuel pin

TABLE I. - MATERIALS FOR REACTOR CALCULATIONS

Material	Density, g/cm^3	Fuel regions			Reflector cooling regions	Pressure vessel	Reflectors and drums			Poison sectors	Shield	Axial plenum
		Zone 1	Zone 2	Zone 3								
	Content, vol. %											
Nitride fuel[a]												
with U^{235}	14.2	33.4	37.7	42.0	-----	-----	----	----	----	--	--	--
with U^{233}	-----	20.6	23.3	26.0	-----	-----	----	----	----	--	--	--
Lithium-7	.49	25.2	25.2	25.2	100.0	-----	10	10	10	5	10	75
T-111[b]	16.72	24.4	24.4	24.4	-----	100.0	----	----	----	--	--	25
Tungsten	19.3	1.5	1.5	1.5	-----	-----	----	----	----	--	--	--
Void												
with U^{235}	-----	15.5	11.2	6.9	-----	-----	10	10	10	10	5	--
with U^{233}	-----	28.3	25.6	22.9	-----	-----	----	----	----	--	--	--
Lithium-6 hydride	.8	----	----	----	-----	-----	----	----	----	--	70	--
Molybdenum	10.2	----	----	----	-----	-----	10.0	30.0	80.0	10	15	--
Boron-10 carbide[c]	2.5	----	----	----	-----	-----	----	----	----	75	--	--
Beryllium oxide	3.02	----	----	----	-----	-----	70.0	50.0	----	--	--	--

[a]Uranium-235 composition: 93.2 percent U^{235}, 6.8 percent U^{238}; U^{233} composition: 98.2 percent U^{233}, 1.1 percent U^{234}, 0.7 percent U^{238}.

[b]By weight percent, composition is 89.2 tantalum, 8.5 tungsten, 2.3 hafnium.

[c]92 percent boron-10 enrichment.

ends and support plate structure. The compositions of the core materials are listed in table I.

CONTROL DRUM AND REFLECTOR DESCRIPTION

Figure 2 shows the geometry for a 10-control-drum configuration. In this figure the spacing h between adjacent drums is 0.52 centimeter and the spacing g between the pressure vessel and control drums is 0.75 centimeter. The radius of the control drum

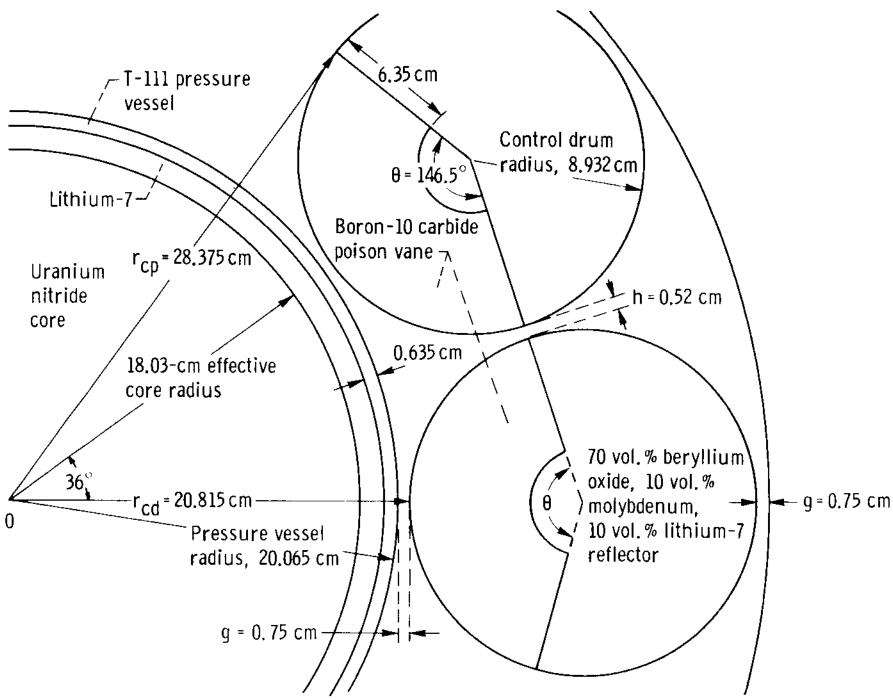

Figure 2. - Geometry for 10-control drum reactor.

r_d is 8.932 centimeters. The pressure vessel radius r_p is the same for all cases (20.065 cm). Other dimensions used in the neutronic calculations are

(1) Radius of reactor to edge of reflector given by $r_p + 2g + 2r_d$

(2) Core center to drum surface, $r_{cd} = r_p + g$

(3) Core center to poison vane edge, $r_{cp} = \left[(r_{cd} + r_d)^2 - r_d^2\right]^{1/2}$

(4) Poison vane angle, $\theta = 2 \cos^{-1}\left[r_d/(r_{cd} + r_d)\right]$

Table II lists dimensions for the various control-drum configurations used in this study. The poison vane is in the form of a sector of an annulus. The thickness of the

TABLE II. - DIMENSIONS FOR DRUM CONFIGURATIONS

Number of drums	Drum radius, r_d, cm	Pressure vessel to drum spacing, g, cm	Drum to drum spacing, h, cm	Poison vane angle, θ, deg	Core center to drum surface, r_{cd}, cm	Core center to poison vane edge, r_{cp}, cm
8	12.695	0.75	0.247	135.5	20.815	31.010
10	8.932	.50	.367	146.5	20.565	28.112
10	8.932	.75	.521	146.5	20.815	28.375
10	8.932	1.00	.676	146.5	21.065	28.636
12	6.847	.75	.625	151.4	20.815	26.802

poison vane (6.35 cm in fig. 1) is a variable as well as the composition of the reflector region. Table I shows the three reflector compositions used; also shown is the composition of the poison vane sector.

A lithium-6 hydride shield, 7.62 centimeters thick, was included in all of the radial calculations as a representative shield material surrounding the reactor; its composition is given in table I.

CALCULATION METHODS

The calculational methods and the justification for the particular energy group structure and models is given in detail in reference 3. The brief description given here is for readers with a working knowledge of the techniques used in neutronic calculations.

The GAM-II program (ref. 4) is used to generate a slowing-down spectrum of fission neutrons interacting with the homogenized core materials. The 99 fine-group cross sections are reduced to 13 broad-group cross sections by spectrum averaging. The GATHER-II program (ref. 5) is used to generate a thermalized spectrum of neutrons that have slowed down in the beryllium oxide reflector. One group ($E \leq 0.414$ eV) cross sections for both the core and reflector are averaged over this spectrum. A separate GATHER-II problem was used for the shield region. GAM-II is also used to generate 13 fast-group cross sections for the reflector region and the shield region. The actual energy groups used are given in reference 3. The TDSN program (ref. 6) is used for all spatial calculations. The S_4P_0 transport-corrected one-dimensional calculations are run in the radial direction with the axial buckling computed from the core height augmented by a 13.5-centimeter axial reflector savings as determined from radial-axial buckling synthesis calculations.

The control-drum absorber elements are incorporated into the calculations by annularizing and homogenizing them with a portion of the reflector. For the drums-in geometry (drums in least reactive position) in figure 1, the annular region is between r_{cp} and r_{cd}. Table II lists the values of r_{cp} and r_{cd} for the various configurations. The materials within this annulus are homogenized by volume averaging. For the drums-out geometry (drums in most reactive position), the same thickness of annulus is maintained and the materials are again smeared on the basis of their volumes. All other regions, for both the drums-in and drums-out geometry, already have azimuthal symmetry and require no further modification.

RESULTS AND DISCUSSION

Excess Reactivity and Reactivity Control Requirements

Table III lists the excess reactivity and reactivity control requirements for an eight-control-drum configuration using both U^{235} and U^{233} fuel. The eight-drum configuration was chosen because the worth of a single drum stuck in its most reactive position is greater than that of the 10- or 12-drum configuration calculated. The required reactivity control for 10- and 12-drum cases is discussed later. The spacings for the example in table III are 0.75 centimeter between drums and pressure vessel and 0.247 centimeter between drums. The absorber vane thickness is 6.35 centimeters. The greater fuel depletion allowance for the U^{233} fueled reactor is due to the reduced loading (23.5 vol. %

TABLE III. - EXCESS REACTIVITY AND REACTIVITY CONTROL REQUIREMENTS FOR EIGHT-DRUM REACTORS

	Fuel type	
	Uranium-235 reactivity, $\Delta k/k$, percent	Uranium-233 reactivity, $\Delta k/k$, percent
Fuel depletion	1.85	2.52
Temperature defect (460 - 1222 K)	1.15	1.15
Long-term fuel expansion	.35	.35
Contingency allowance	1.00	1.00
Excess reactivity	4.35	5.02
Normal shutdown	2.00	2.00
1 of 8 drum stuck	.81	1.07
Control requirement	7.16	8.09
Multiplication factor	1.046	1.053

compared with 38 vol. % for the U^{235} reactor). The fuel depletion allowance is for 50 000 hours at 2.17 thermal megawatts. Of the 1.15 percent $\Delta k/k$ for the temperature defect (460 to 1222 K), 0.9 percent $\Delta k/k$ was calculated for core, coolant, and structural expansion, and 0.25 percent $\Delta k/k$ was estimated for Doppler defect. A contingency allowance of 1.0 percent $\Delta k/k$ was assumed. It includes manufacturing tolerances, fuel loading uncertainties and calculational uncertainties. Calculational uncertainties are most difficult to estimate in the absence of experiments similar to the configurations calculated in this study. Thus, the requirements listed in table III are tentative but serve as a reasonable list to use as minimum reactivity control that should be available.

The following section shows the reactivity control available as calculated for the various cases examined in this study.

Calculated Reactivity Control

In figures 3 to 6 data are presented for both U^{235} and U^{233} fueled reactors.

Effect of number of control drums. - Figure 3 shows the reactivity control calcu-

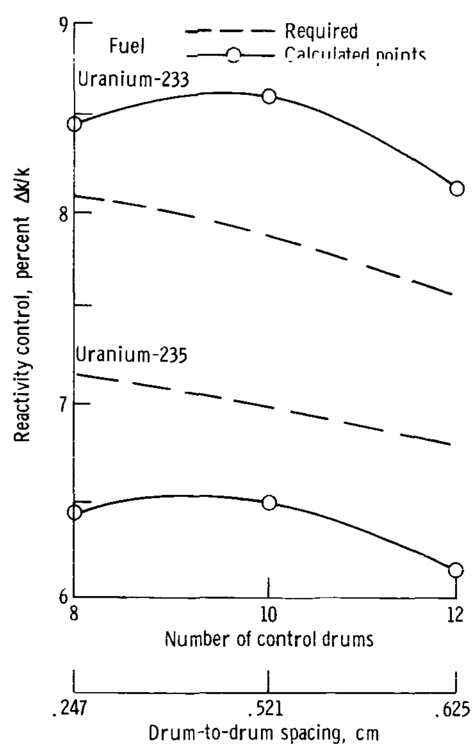

Figure 3. - Comparison of required and calculated reactivity control for cores fueled with uranium-235 and with uranium-233. Reflector composition (in vol. %), 70 beryllium oxide, 10 lithium-7; poison vane thickness, 6.35 centimeters; pressure-vessel-to-drum spacing, 0.75 centimeter.

lated points for eight, 10, and 12 control drums used for the reactor. These points have been connected by solid lines. For these curves the drum to pressure vessel spacing is 0.75 centimeter; the drum-to-drum spacing is shown in the figure. The poison vane thickness is 6.35 centimeters. The reflector composed of 70 volume percent beryllium oxide (BeO), 10 volume percent molybdenum (Mo), and 10 volume percent Li^7 was used. It should be noted that, though the 10-drum case shows the most reactivity control for both types of uranium fuel, the variation with number of drums is small. Furthermore, the reactivity control calculated for the U^{235} fuel fails to meet the control requirement (dashed curve) by -0.8 to -0.5 percent $\Delta k/k$. The U^{233} fueled reactor exceeds the control requirement by 0.4 to 0.7 percent $\Delta k/k$. Without experimental verification or verification with better calculations the reactivity control for both these reactors should be considered marginal.

If the requirement of an L/D of 1.04 were relaxed, acceptable reactivity control for this type of reactor could be obtained. The effect of increasing L/D on reflector worth for fast-spectrum reactors is presented in reference 7. Using the parametric curves in reference 7, it is found that an increase in reflector worth of about 6 percent $\Delta k/k$ could be expected for this size reactor if the L/D were increased to 1.4 while maintaining the same core volume. Of this 6 percent $\Delta k/k$ increase in total radial reflector worth, about one third would be controllable by the control drums. Thus about 2 percent $\Delta k/k$ increase in reactivity control could be expected.

Control drum size could be important depending on mission requirements for the reactor. The reactor diameter (including reflector) would be about 94.0 centimeters for the eight-drum case, 79.0 centimeters for the 10-drum case, and only 70.5 centimeters for the 12-drum case.

Effect of control drum spacings. - Figure 4 shows the reactivity control for the 10-drum configuration with 6.35-centimeter-thick poison vanes in the 70 volume percent BeO, 10 volume percent Mo, 10 volume percent Li^7 reflector as a function of the spacing between the drum and pressure vessel. The control drum diameters were not changed; therefore, the spacings between adjacent drums vary (table II). The curves indicate that it is important to try to design the reactor with minimum distance between the control drums and the core. An increase of about 1 percent $\Delta k/k$ in control reactivity for each half-centimeter decrease in the pressure-vessel-to-drum spacing can be realized for reactors with either type of fuel.

Effect of poison sector thickness. - Figure 5 shows the reactivity control calculated as a function of the thickness of the poison in the annular sector of the control drums. The 10-drum geometry, with 0.75 centimeter spacing between drums and pressure vessel, in the 70 volume percent BeO, 10 volume percent Mo, and 10 volume percent Li^7 reflector was used. The maximum thickness (8.932 cm) is obtained with a full sector of the drum but only a small increase in reactivity control is noted compared with 6.35 centimeters used to plot figures 3 and 4.

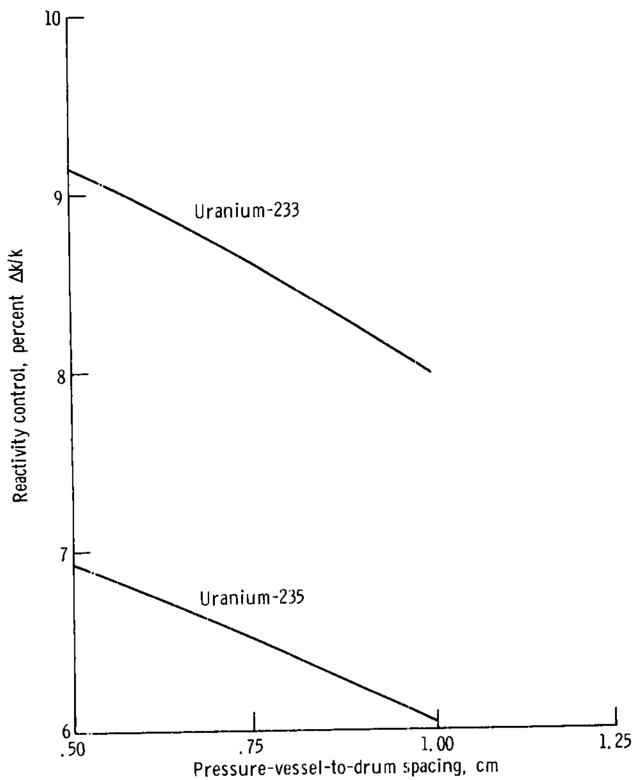

Figure 4. - Effect of pressure-vessel-to-drum spacing on reactivity control for 10 control drums. Control drum radius, 8.932 centimeters; poison vane thickness, 6.35 centimeters; reflector composition (in vol. %), 70 beryllium oxide, 10 molybdenum, 10 lithium-7.

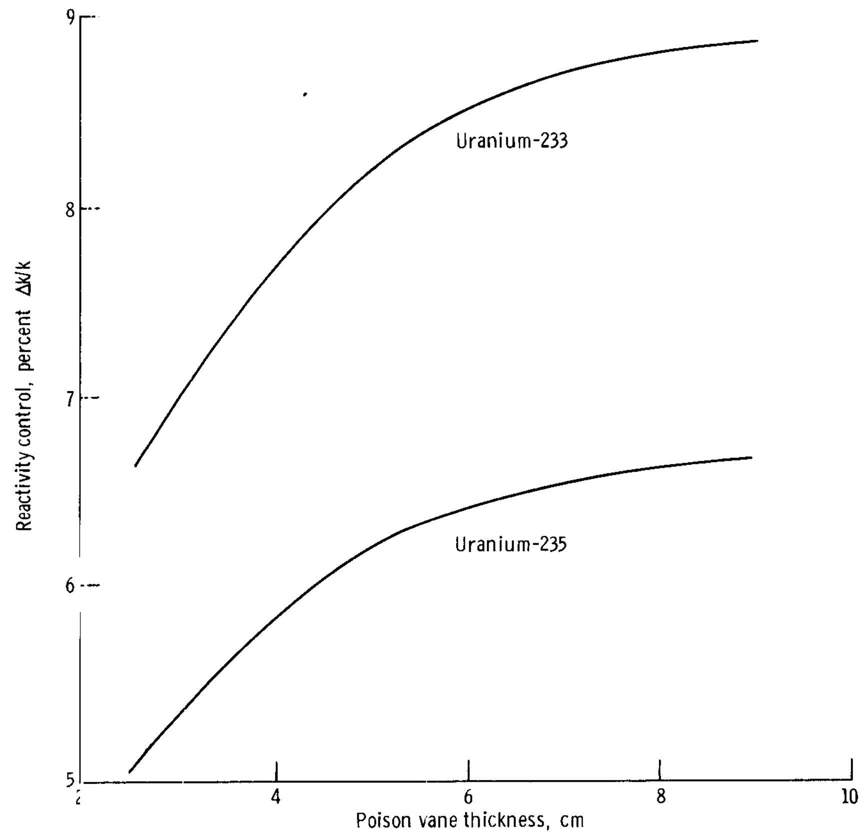

Figure 5. - Effect of poison vane thickness on reactivity control. Number of control drums, 10; pressure-vessel-to-drum spacing, 0.75 centimeter; reflector composition (in vol. %), 70 beryllium oxide, 10 molybdenum, 10 lithium-7.

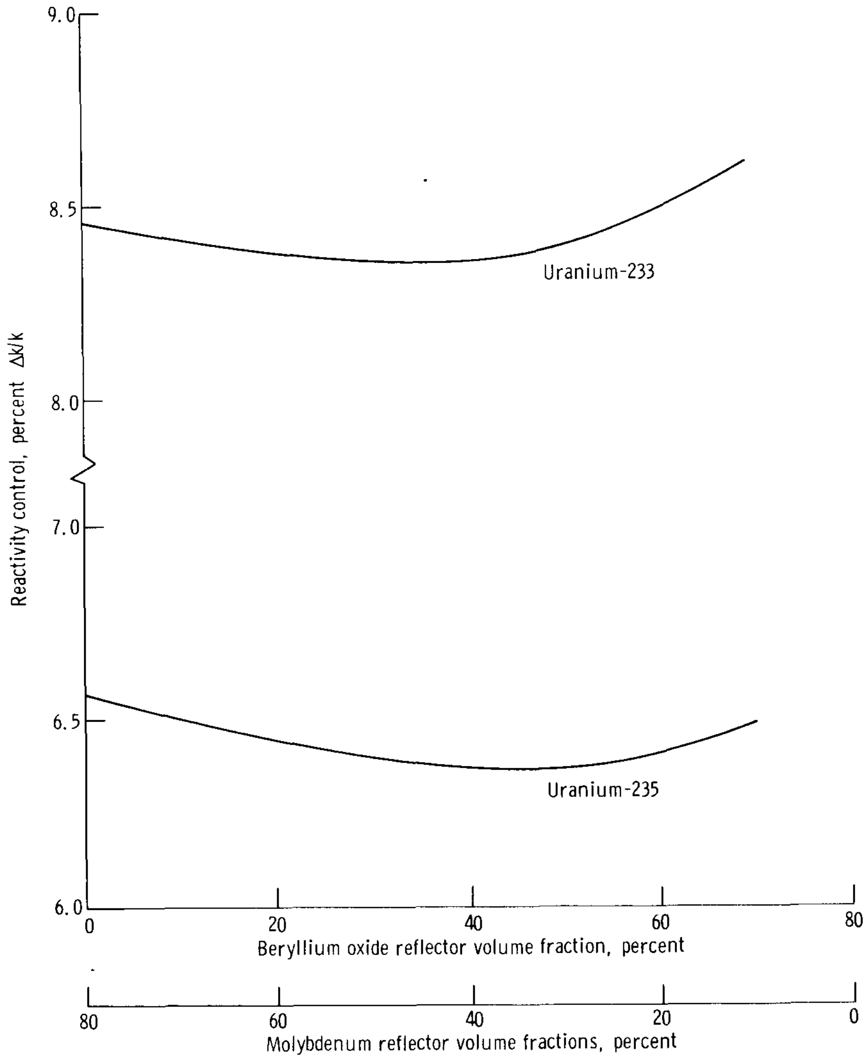

Figure 6. - Effect of varying reflector composition on reactivity control for 10 drums. Poison vane thickness, 6.35 centimeters; pressure-vessel-to-drum spacing, 0.75 centimeter.

Effect of reflector composition. - Figure 6 shows the available reactivity control as a function of reflector composition. The 10-drum configuration with 6.35 centimeter poison sector thickness and with the same spacings as in figure 5 was used. The reflector composition varied from 80 volume percent Mo and 10 volume percent Li^7 to 70 volume percent BeO, 10 volume percent Mo, and 10 volume percent Li^7. Thus, 10 volume percent Li^7 and at least 10 volume percent Mo appeared in all compositions. Only a small variation in reactivity control is noted for each fuel type as a function of reflector composition. The variation is only about 0.3 percent $\Delta k/k$ for the U^{235} fueled reactor and 0.5 percent $\Delta k/k$ for the U^{233} fueled reactor. The reason for the decrease in the control reactivity for reflector compositions of about 50 volume percent BeO, 30 volume percent Mo, and 10 volume percent Li^7 is not understood since a detailed analysis of the spectra and importance functions was not done. The important point is that the reactivity control is about the same whether the reflector is basically BeO or basically Mo. This equivalence was not surprising since reference 2 came to a similar conclusion when these reflector materials in similar compositions were used in radial reflectors.

Multiplication Factors

Table IV itemizes all the cases calculated. Much of the reactivity control data in the table have been presented in figures 3 to 6. Only the drums-out multiplication factors are shown; the drums-in values are not necessary but could be calculated simply from the data given in the table. The multiplication factors in table IV are about 4 to 5 percent Δk larger than required (table III). One method of reducing the excess reactivity is by reducing the amount of fuel in the fuel pins. Not only would this reduction in fuel lower clad stress due to fuel swelling, but the control reactivity would be enhanced because the core would be more transparent in terms of neutron mean-free paths and the reflector worth would be increased. A 0.6-percent $\Delta k/k$ change in reactivity for a 1-percent change in uranium nitride loading has been calculated; the value is essentially the same for both types of fuel in these reactors. For example, using this relation the average fuel fraction of case 4 in table IV decreases 2.3 volume percent (to 35.7 vol. %) for the U^{235} fuel for a multiplication factor of 1.046 (table III). Similarly, for the U^{233} reactor a reduction of 1.5 volume percent (to 22.0 vol. %) gives the required multiplica-

TABLE IV. - ANALYTICAL RESULTS

Case	Reflector composition, vol. % (a)	Number of drums	Pressure-vessel-to-drum spacings, cm	Vane thickness, cm	Type of fuel			
					Uranium-235		Uranium-233	
					Multiplication factor	Reactivity, $\Delta k/k$, percent	Multiplication factor	Reactivity, $\Delta k/k$, percent
1	70 BeO, 10 Mo, 10 Li^7	8	0.75	6.35	1.088	6.43	1.100	8.47
2		10		2.50	1.085	5.03	1.097	6.62
3				4.45	1.085	6.02	1.096	7.95
4				6.35	1.085	6.50		8.58
5				8.93	1.085	6.71		8.87
6			.50	6.35	1.084	6.93		9.16
7			1.00	6.35	1.085	6.03		7.96
8		12	.75	2.50	1.082	5.05	1.092	6.65
9		12		6.35	1.080	6.17	1.090	8.14
10	50 BeO, 30 Mo, 10 Li^7	10		6.35	1.082	6.37	1.092	8.39
11	80 Mo, 10 Li^7	10		6.35	1.081	6.56	1.088	8.45

[a]10-percent void.

tion factor of 1.053. With U^{235} the fuel loading is about 60 percent greater than with U^{233}. Calculations were not done to determine what enhancement of the reactivity control would occur due to these fuel reductions.

Radial Power Distributions

Figure 7 shows relative radial power distributions obtained from drums-out calculations for both the U^{233} fueled reactor (solid lines) and the U^{235} fueled reactor (dashed line). The 70 volume percent BeO, 10 volume percent Mo, and 10 volume percent Li^7 reflector with 10 control drums, 6.35 centimeter vane thickness, and 0.75 centimeter pressure vessel-to-drum spacing is used for both cases. The radial power distribution is more uniform for the U^{233} fueled reactor than for the U^{235} fueled reactor. The local-to-average power density ratio $P_R/\overline{P}_R$ has minimum and maximum values of 0.932 and 1.08 for the U^{233} reactor compared with 0.888 and 1.127 for the U^{235} reactor. The more uniform power profile for the U^{233} reactor can be attributed directly to the smaller fuel loading requirement and the resultant longer mean-free neutron paths which tend to enhance the reflector worth.

Note that there is only a small power spike at the core edge. The tantalum alloy pressure vessel effectively filters out the lower energy neutrons that slow down in the reflector. The small amount of molybdenum (10 vol. %) in the reflector is also effective in capturing lower energy neutrons. The result is a greatly reduced power spike at the

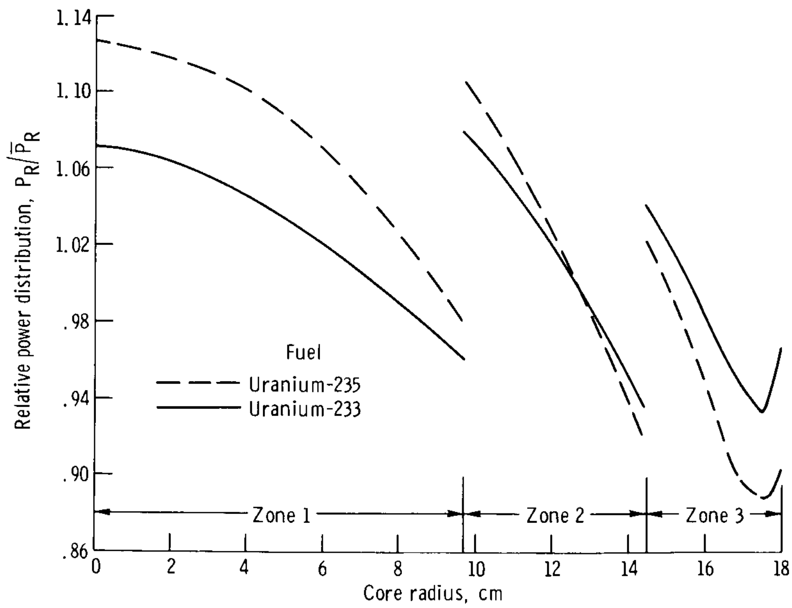

Figure 7. - Relative radial power distributions for reactors with drums in most reactive position.

core edge compared with what would exist with a pure BeO reflector immediately adjacent to the core. Additional discussion of the effect on neutron spectrum due to the presence of absorptive cladding materials in BeO reflectors and absorptive pressure vessels between core and reflector is given in reference 2.

SUMMARY OF RESULTS

A study has been conducted to compare the reactivity control characteristics of equal-size reactor cores with length-to-diameter ratios of 1.04 and using uranium nitride fuel enriched in the uranium-233 isotope or enriched in the uranium-235 isotope. Poisoned control drums in the radial reflector are used. The reactor core contains 24.4 volume percent T-111, a tantalum alloy.

Reactivity control is marginal with either type of fuel. For example, with uranium-235, reactivity control calculated for a typical configuration (10 drums, 6.35-cm thick vanes, and spacings of 0.52 cm between drums and 0.75 cm between drums and pressure vessel) is 6.50 percent $\Delta k/k$ using a reflector composed of 70 volume percent beryllium oxide, 10 volume percent molybdenum, and 10 volume percent lithium 7. The required reactivity contorl is 7.0 percent $\Delta k/k$.

Though the reactivity control requirements are larger by 0.9 percent $\Delta k/k$ for the same reactor fueled with the uranium-233 isotope, the available reactivity control is also larger (8.6 percent $\Delta k/k$). However, the calculated reactivity control is only 0.7 percent $\Delta k/k$ larger than required. Unless this value can be substantiated, the reactivity control should be considered marginal. With uranium-235, the average fuel loading is about 60 percent greater than if uranium-233 is used for the fuel.

Also, reducing the spacing between control drums and pressure vessel without changing drum size can increase reactivity control at the rate of about 2 percent $\Delta k/k$ per centimeter. With the one-dimensional radial model used in all of the calculations, it is found that a full sector of neutron absorber ($B_4^{10}C$) in the control drum provides the maximum reactivity control, but the maximum is only slightly larger than that obtained using an annular sector of poison 6.35 centimeters thick.

Increasing the number of control drums from eight to 12 results in a reduction of 23.5 centimeters in reactor diameter. Use of 10 drums instead of eight saves 15.0 centimeters in reactor diameter. Only a small variation of less than 0.5 percent $\Delta k/k$ in the calculated reactivity control was found as the number of control drums was varied.

The reflector composition was varied by replacement of beryllium oxide by molybdenum. A constant 10-volume-percent lithium-7, 10-volume-percent void was included in all reflectors; the remaining 70 volume percent of the reflector was varied. The variation in reactivity control was only about 0.3 percent $\Delta k/k$ for the uranium-235 fueled reactor and about 0.5 volume percent $\Delta k/k$ for the uranium-233 reactor.

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